

Grand Challenges in Energy



BES Science in 2018
Spirit of Iran Thomas Symposium
Arlington, Va.
May 29, 2003

R. E. Smalley
Rice University

Iran Thomas

Dec 2, 2002

I'm more concerned with the next 30 to 50 years and with 2 of the 4 horsemen of the apocalypse -- war and famine - that I believe will ride in soon. It's inconceivable to me that we will continue business as usual even for another generation. Demand for oil is just going to overwhelm everything else. The US will not be able to maintain peace without wrecking its economy.

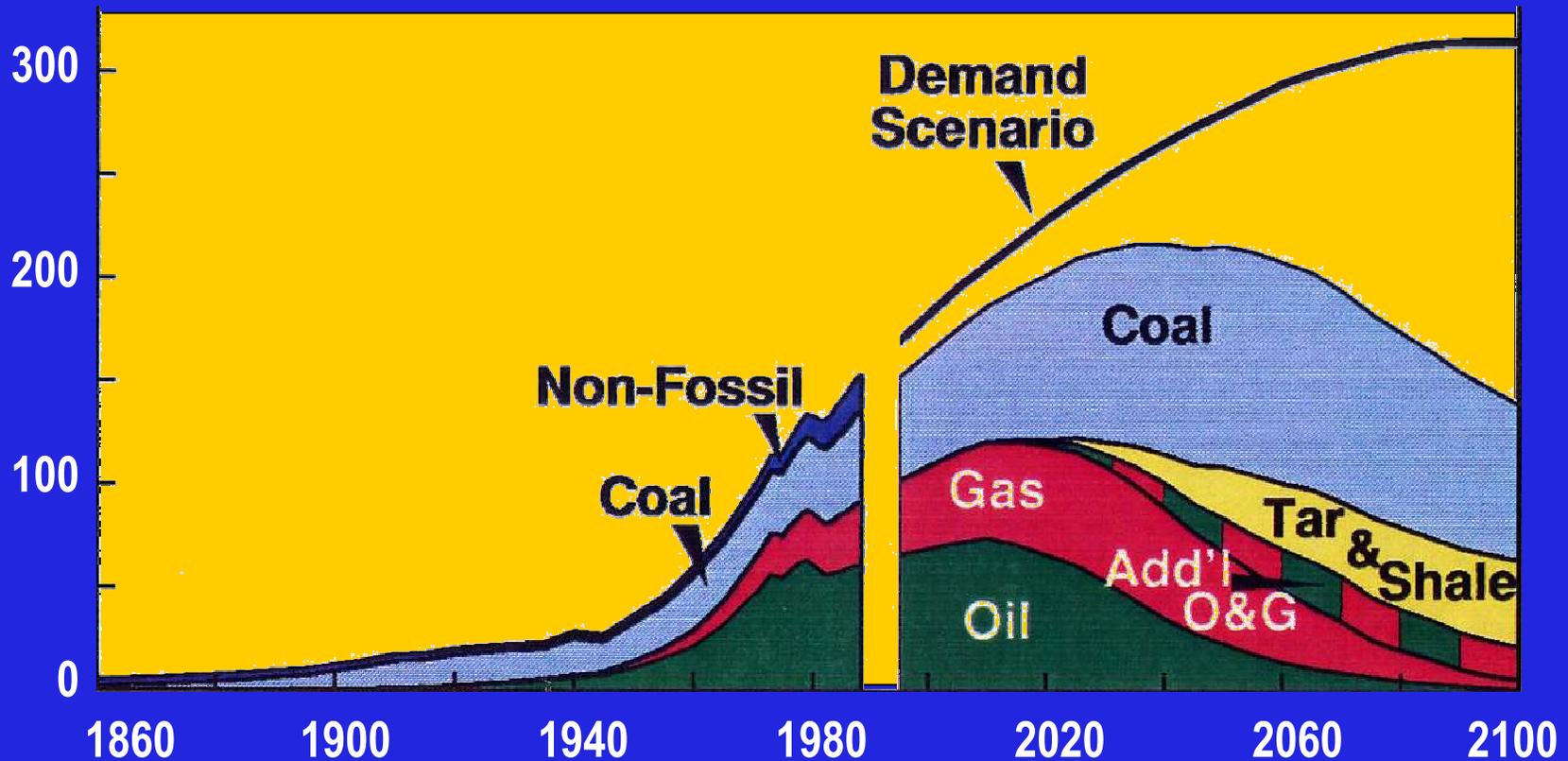
Other countries will militarize and challenge the Pax Americana to guarantee access to oil. Famine will drive Africa to bang on Europe's doors. The East, led by India and China, which will be becoming economic giants and are members of the nuclear club, will clamor for oil. Russia will try to play China and Europe off each other. Japan will get paranoid. Europe will go after something somewhere. Pity the small Asian and African countries with oil. The Middle East will become even more coveted than it is now. Maybe I'm exaggerating, but history does not give me cause to be very optimistic.

I think we have to get much smarter faster than the timescale for climate change would imply.

Iran

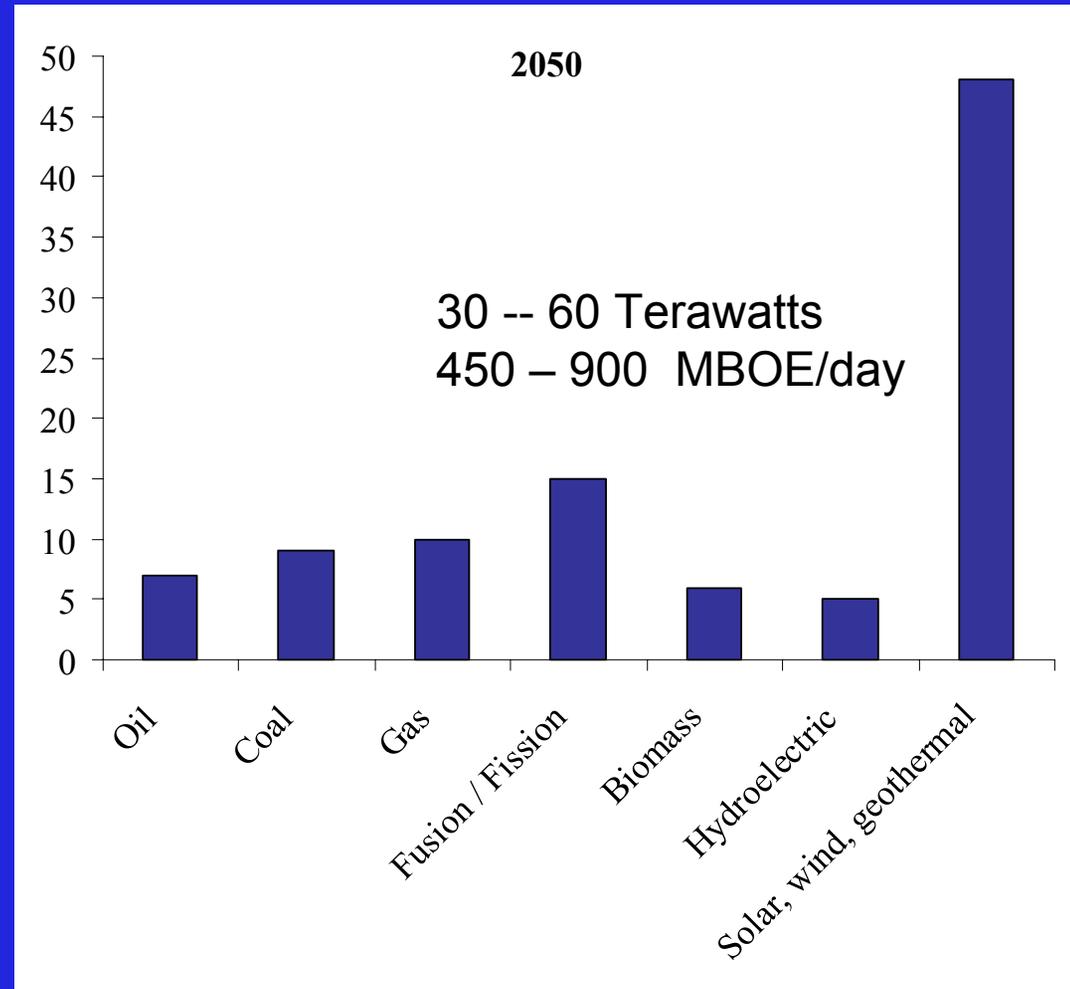
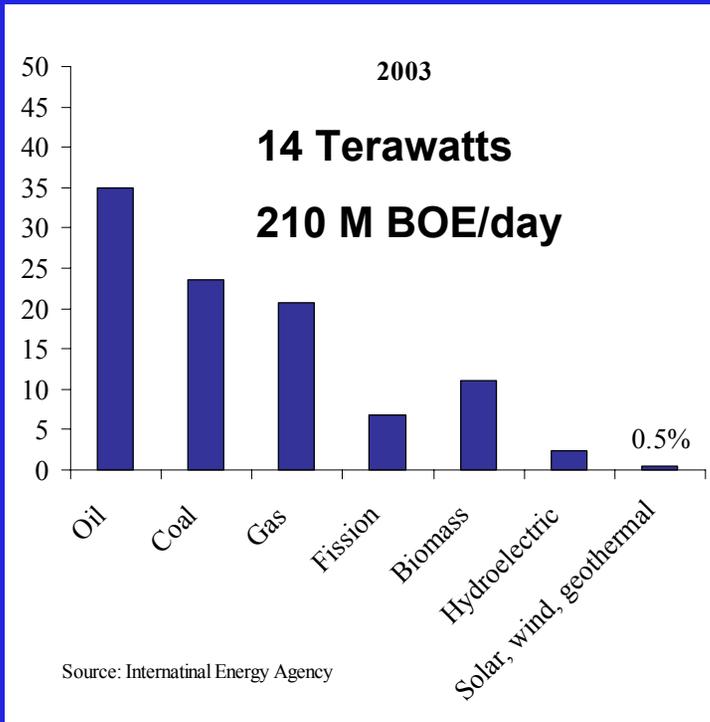
World Energy

Millions of Barrels per Day (Oil Equivalent)



Source: John F. Bookout (President of Shell USA) , "Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10, 1985. Episodes, vol 12, 257-262 (1989).

The ENERGY REVOLUTION (The Terawatt Challenge)



The Basis of Prosperity

20st Century = OIL

21st Century = ??

IRAN THOMAS 80TH BIRTHDAY CELEBRATION
2018

one of our birthday gifts:

Armchair Quantum Wire

1GW power* transmission cable dedicated to connect wind farms in N. Dakota to Argonne National Lab.

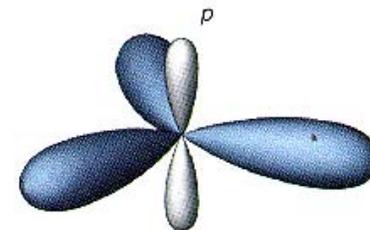
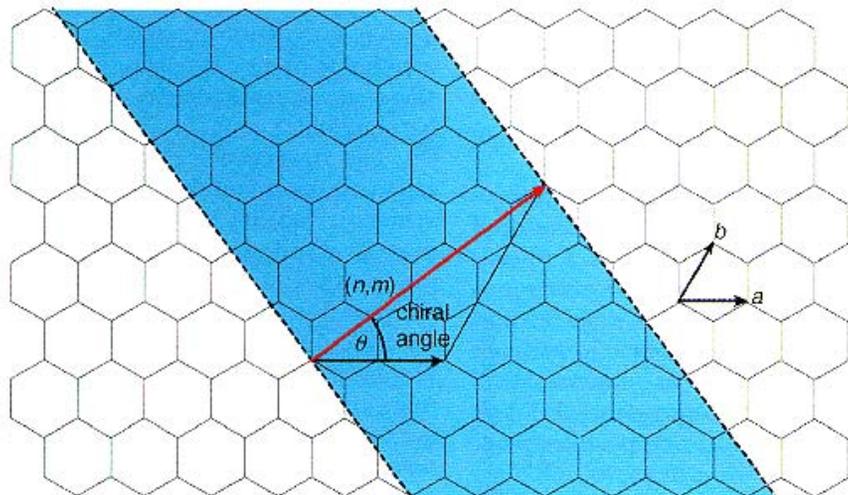
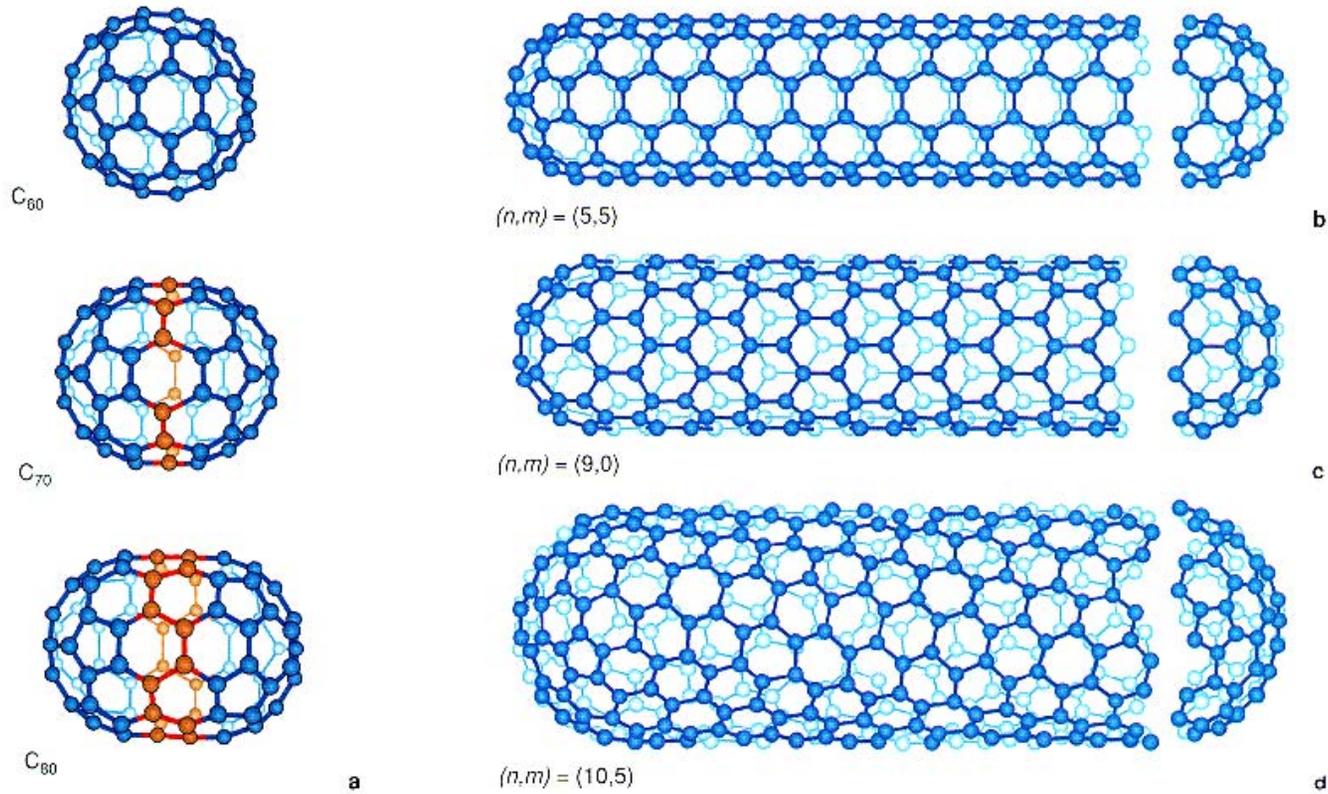
Wind machines and power lines made with new swnt materials developed by DOE Nanotechnology Labs, a result of the

SWNT GRAND CHALLENGE of the NNI taken up by DOE in 2003.

* 1 GW power used for new \$100B Dark Energy National Users Facility at ANL.

THE SWNT GRAND CHALLENGE

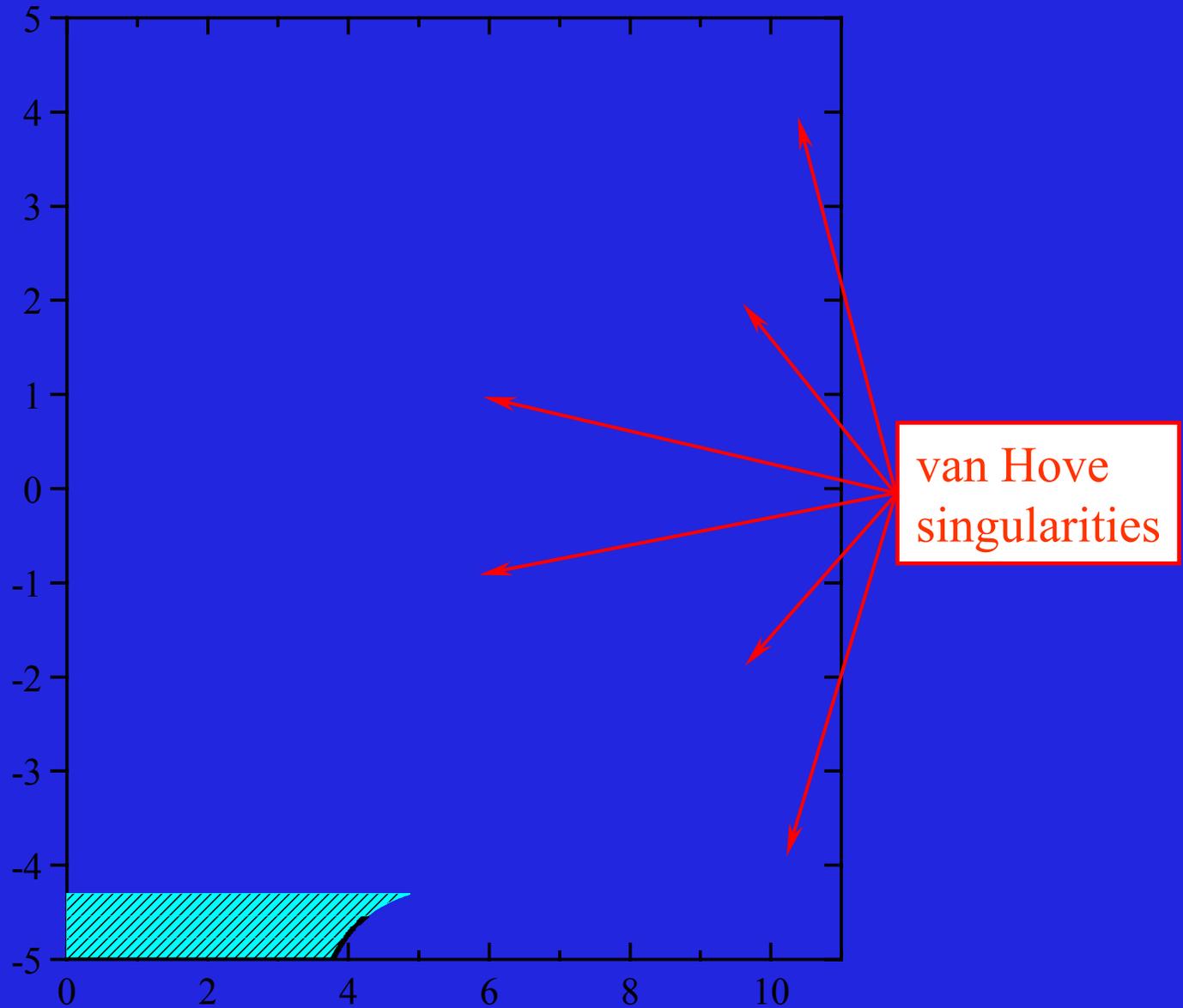
- Develop Methods to produce swnt with any single, selected n,m value
- In great purity, in large amounts, cheaply
- Understand their physics and chemistry both as individuals and arrays
- Learn to spin continuous fibers, membranes, composites, circuits, etc.
- Learn to grow to continuous single crystals



e

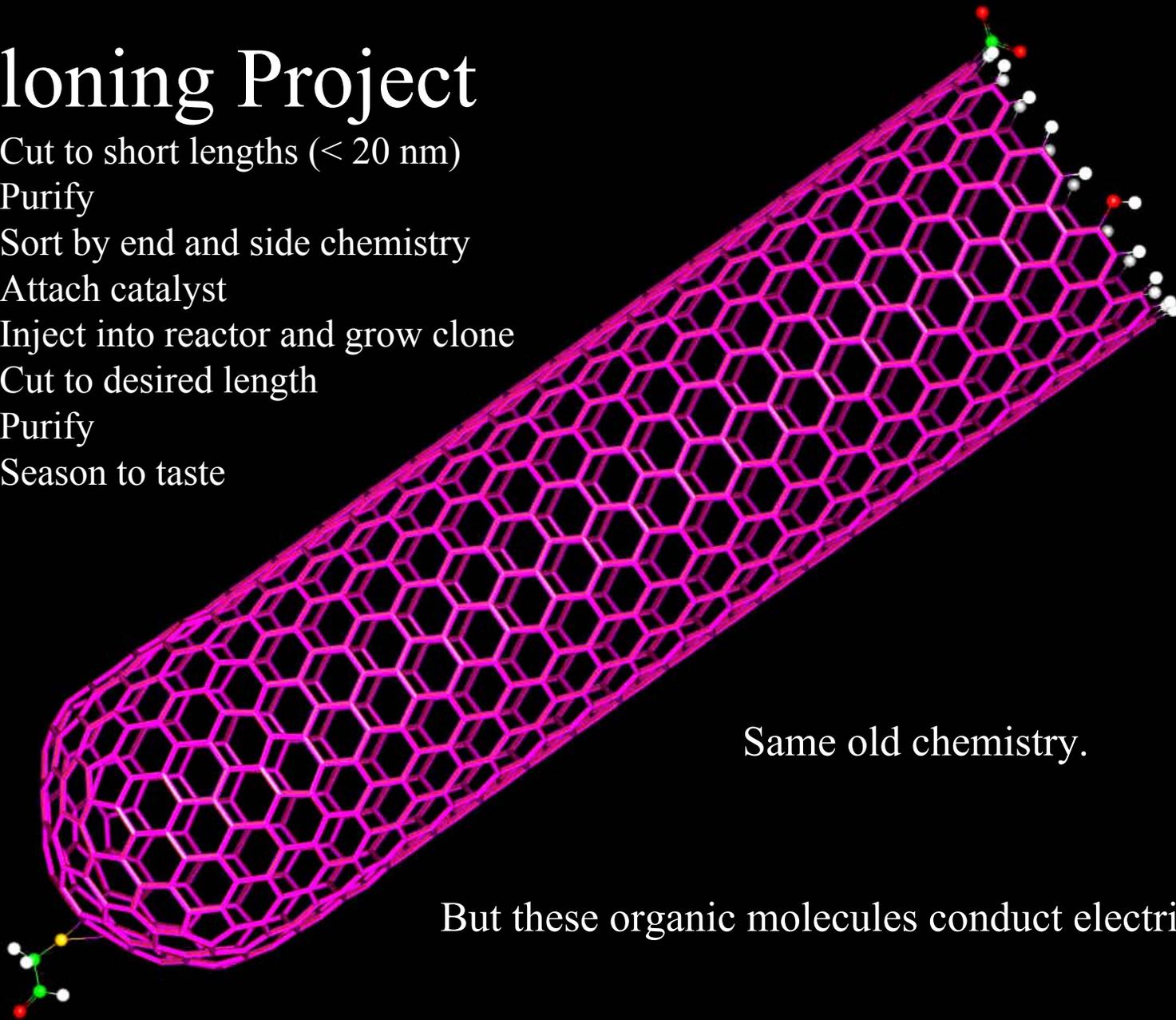
f

Electronic States of Semiconducting SWNT



Cloning Project

1. Cut to short lengths (< 20 nm)
2. Purify
3. Sort by end and side chemistry
4. Attach catalyst
5. Inject into reactor and grow clone
6. Cut to desired length
7. Purify
8. Season to taste



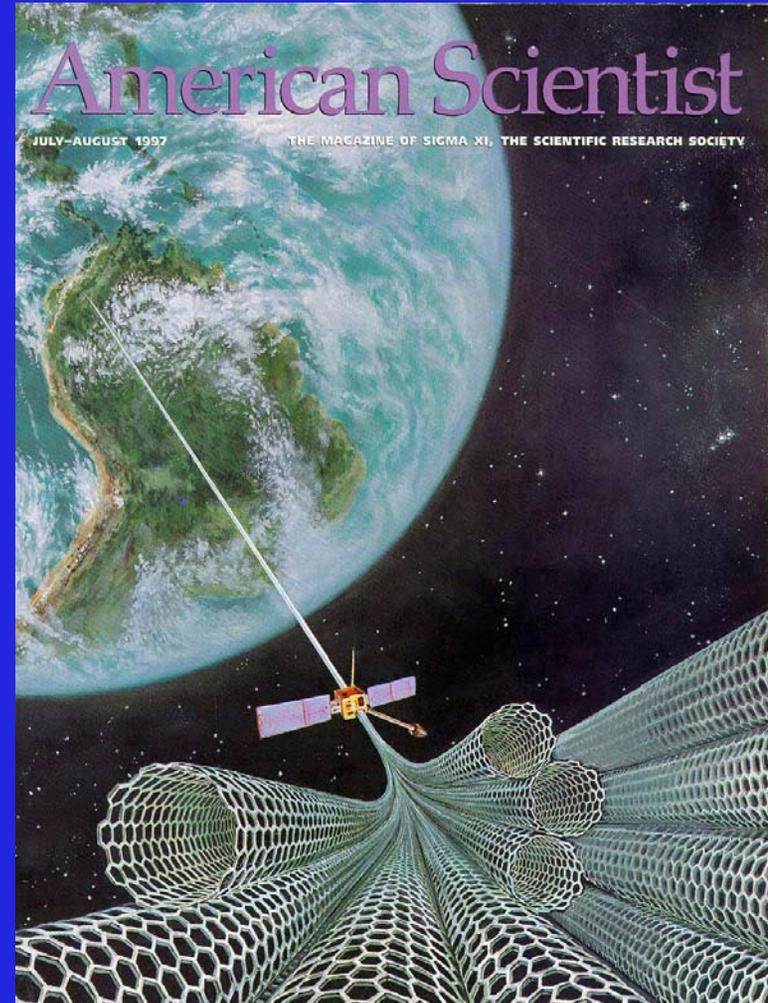
Same old chemistry.

But these organic molecules conduct electricity!

ARMCHAIR WIRE PROJECT

**ELECTRICAL CONDUCTIVITY
OF COPPER AT 1/6 THE WEIGHT
WITH NEGLIGIBLE EDDY CURRENTS**

- cut swnt to short lengths
- select out the (n,m) tubes with $n=m$ (the “armchair tubes”)
- grow them to ~ 10 micron lengths
- spin them into continuous fibers



Energy Nanotech Grand Challenges

1. Photovoltaics -- drop cost by 100 fold.
2. Photocatalytic reduction of CO₂ to methanol.
3. Direct photoconversion of light + water to produce H₂.
4. Fuel cells -- drop the cost by 10-100x + low temp start.
5. Batteries and supercapacitors -- improve by 10-100x for automotive and distributed generation applications.
6. H₂ storage -- light weight materials for pressure tanks and LH₂ vessels, and/or a new light weight, easily reversible hydrogen chemisorption system
7. Power cables (superconductors, or quantum conductors) with which to rewire the electrical transmission grid, and enable continental, and even worldwide electrical energy transport; and also to replace aluminum and copper wires essentially everywhere -- particularly in the windings of electric motors and generators (especially good if we can eliminate eddy current losses).

Energy Nanotech Grand Challenges

8. **Nanoelectronics to revolutionize computers, sensors and devices.**
9. **Nanoelectronics based Robotics with AI to enable construction maintenance of solar structures in space and on the moon; and to enable nuclear reactor maintenance and fuel reprocessing.**
10. **Super-strong, light weight materials to drop cost to LEO, GEO, and later the moon by > 100 x, to enable huge but low cost light harvesting structures in space; and to improve efficiency of cars, planes, etc.**
11. **Thermochemical processes with catalysts to generate H_2 from water that work efficiently at temperatures lower than 900 C.**
12. **Nanotech lighting to replace incandescent and fluorescent lights**
13. **NanoMaterials/ coatings that will enable vastly lower the cost of deep drilling, to enable HDR (hot dry rock) geothermal heat mining.**
14. **CO_2 mineralization schemes that can work on a vast scale, hopefully starting from basalt and having no waste streams.**

THE SWNT GRAND CHALLENGE

- Develop Methods to produce swnt with any single, selected n,m value
- In great purity, in large amounts, cheaply
- Understand their physics and chemistry both as individuals and arrays
- Learn to spin continuous fibers, membranes, composites, circuits, etc.
- Learn to grow to continuous single crystals

IRAN THOMAS 80TH BIRTHDAY CELEBRATION
2018

one of our birthday gifts:

Armchair Quantum Wire

1GW power* transmission cable dedicated to connect wind farms in N. Dakota to Argonne National Lab.

Wind machines and power lines made with new swnt materials developed by DOE Nanotechnology Labs, a result of the

SWNT GRAND CHALLENGE of the NNI taken up by DOE in 2003.

* 1 GW power used for new \$100B Dark Energy Nat. Users Facility at ANL.

PRIMARY ENERGY SOURCES

Alternatives to Oil

TOO LITTLE

- Conservation / Efficiency -- not enough
- Hydroelectric -- not enough
- Biomass -- not enough
- Wind -- not enough
- Wave & Tide -- not enough

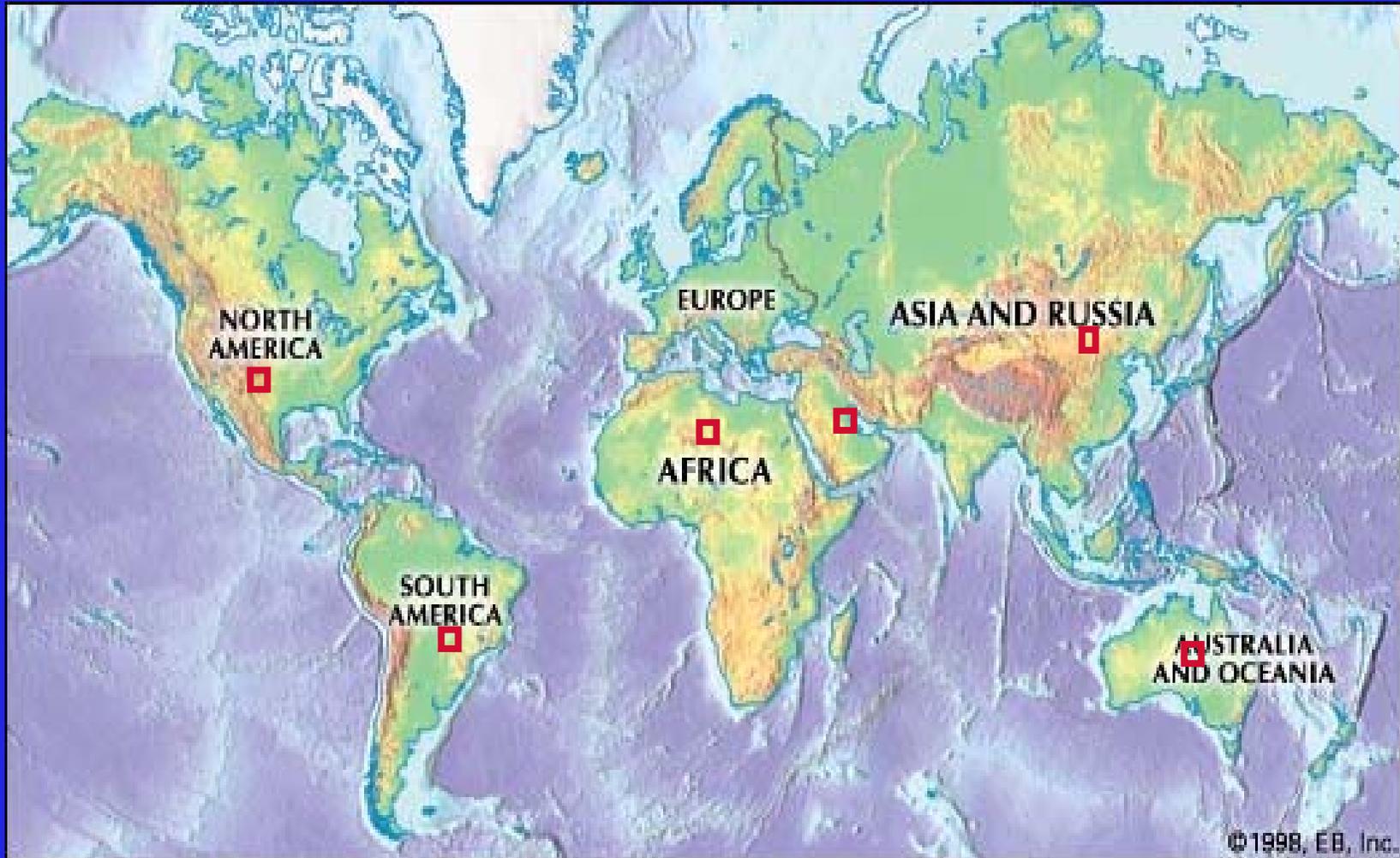
CHEMICAL

- Natural Gas -- sequestration?, cost?
- Clean Coal -- sequestration?, cost?

NUCLEAR

- Nuclear Fission -- radioactive waste?, terrorism?, cost?
- Nuclear Fusion -- too difficult?, cost?
- Geothermal HDR -- cost ? , enough?
- Solar terrestrial -- cost ?
- Solar power satellites -- cost ?
- Lunar Solar Power -- cost ?

Solar Cell Land Area Requirements



6 Boxes at 3.3 TW Each = 20 TWe

